PHYSICS 665. Topology in Modern Quantum Physics and Field Theory. Spring 2022

Instructor: Dr Andriy Nevidomskyy, Assoc. Professor, Dept. of Physics and Astronomy, Rice University.
Course Credit: 3 semester hours.
Lectures: Tue/Thu, 1:00pm-2:15pm.
Format: Assuming the current status quo regarding the Covid-19 pandemic, the instruction will be face-to-face in the Spring semester 2022.
Grading: grades will be assigned based on the homeworks and a presentation that each student will be asked to give (instructor will provide a list of topics that students may choose from). A final exam may also be given.

Course Description

Topology plays an increasingly important role in modern quantum physics, and its applications to a variety of topics range from the theory of liquid crystals to topological defects in quantum field theory. This course will introduce some key notions from topology, such as homotopy and homology, and differential geometry and discuss their applications in quantum physics, from the theory of vortices in superconductors, to monopoles in non-Abelian gauge theories, to instantons in Yang–Mills theory. The course also covers the concepts of topological insulators and superconductors that have become an important part of the vocabulary of modern condensed matter physics. The course may be useful for students pursuing research in condensed matter and AMO physics, as well as high-energy physicists interested in topological defects in quantum field theory.

Prerequisites: Solid knowledge of quantum mechanics (equivalent to graduate PHYS 521) is required. It *is* possible to take the present course without prior exposure to quantum field theory (QFT), however acquaintance with the latter is desirable, for instance in the form of either PHYS 622 ("QFT") or PHYS 664 ("Many-body formalism"), or equivalent courses at other institutions.

Knowledge of differential geometry (for instance MATH 401) will be advantageous but is not required. Similarly, familiarity with point-set topology and its basic concepts (for instance MATH 443) would be useful but is not essential.

Objectives: This course is geared primarily towards aspiring theoretical physicists, with the goal to expose them to some of the modern mathematical and field-theoretical tools in quantum physics. This said, the first part of the course (covering non-interacting topological insulators and superconductors) may be suitable to any graduate student, not necessarily a theorist, interested to learn about the topological phases of matter, which have garnered much attention of condensed matter physicists over the past 15 years.

Learning outcomes: To understand the appearance of topological phases of quantum matter and the role of symmetries therein, with specific applications to topological insulators in 2 and 3 spatial dimensions. To grasp basic ideas behind the notion of topological defects in quantum field theories. To gain familiarity with the mathematical concepts in differential geometry and topology, and their role in modern quantum physics.

Recommended Texts:

1. T. Frankel, *The Geometry of Physics: An Introduction* (Cambridge Univ. Press, 1997);
2. A. Altland and B. Simons, *Condensed Matter Field Theory*, esp. Ch. 9 (Cambridge Univ. Press, 2010).
3. M. Shifman, *Advanced Topics in Quantum Field Theory* (Cambridge Univ. Press, 2012).
4. K. Jänich, *Topology* (Undergraduate Texts in Mathematics, Springer, 1994).